Chapter 3

System Overview

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Acronyms

AMPS	Advanced Mobile Phone System
BS	Base Station
CDMA	Code Division Multiple Access
CTIA	Cellular Telecommunications Industry Association
DAMPS	Digital Advanced Mobile Phone System
DTMF	Dual Tone Multi Frequency
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile communications
HLR	Home Location Register
ISDN	Integrated Services Digital Network
MS	Mobile Station (Cellular phone)
MSC	Mobile Switching Center (see MTX also)
MTSO	Mobile Telephone Switching Office
MTX	Mobile Telephone Exchange (see MSC also)
NADC	North American Digital Communications (IS–54 DAMPS)
PCH	Paging Channel
PN Code	Pseudo random Noise Code
PSTN	Public Switched Telephone Network
RF	Radio Frequency
SAT	Supervisory Audio Tone (5970, 6000 and 6030 Hz)
ST	Signaling Tone (10 kHz)
TCH	Traffic CHannel
TS	Time Slot
VLR	Visitor Location Register
VOCODER	VOice COder DEcodeR
VOCODER	VOice CODER

Cellular History

Mobile Radios have been in use for approximately 70 years and the cellular concept was conceived in the 1940s. Public cellular mobile radio was not introduced in the US until 1983.

In the beginning of the twentieth century, mobile radios were limited to shipboard use due to the high power requirements and bulky tube radio technology. Automotive systems in the 1920s operated on 6 volt batteries with a limited storage capacity.

One of the first useful means of automotive mobile radio occurred in 1928 by the Detroit police department. Transmission was broadcast from a central location and could only be received by the mobile police radios.

Introduction of the first two way mobile application was delayed until 1933. This simplex AM (Amplitude Modulation) push to talk system was introduced by the police department in Bayonne, New Jersey. The first FM (Frequency Modulation) mobile transmission (two frequency simplex) was used by the Connecticut State Police at Hartford in 1940.

The first step towards mobile radio connection with the land line telephone network was established in St. Louis in 1946. It was called an “urban” system and only supported three channels.

In 1976, New York City had only 12 radio channels that supported 545 subscribers with a waiting list of 3700.

In the 1970s, available cellular spectrum was constrained to frequencies above 800 MHz due to equipment design limitations and poor radio propagation characteristics at frequencies above 1–GHz, this resulted in the allocation of the 825–890 MHz region.

In 1974, 40 MHz of spectrum was allocated for cellular service and in 1986, an additional 10 MHz of spectrum was added to facilitate expansion. The present frequency assignments for the US Cellular system mobile phone is 824.040–848.970 MHz transmit and 869.040–893.970 MHz receive These bands have been frequency divided (FDMA) into 30 kHz channels. This results in a maximum capacity of 832 channels. These channels were then divided into two groups with 416 channels assigned to each system.

Code Division Multiple Access (CDMA)

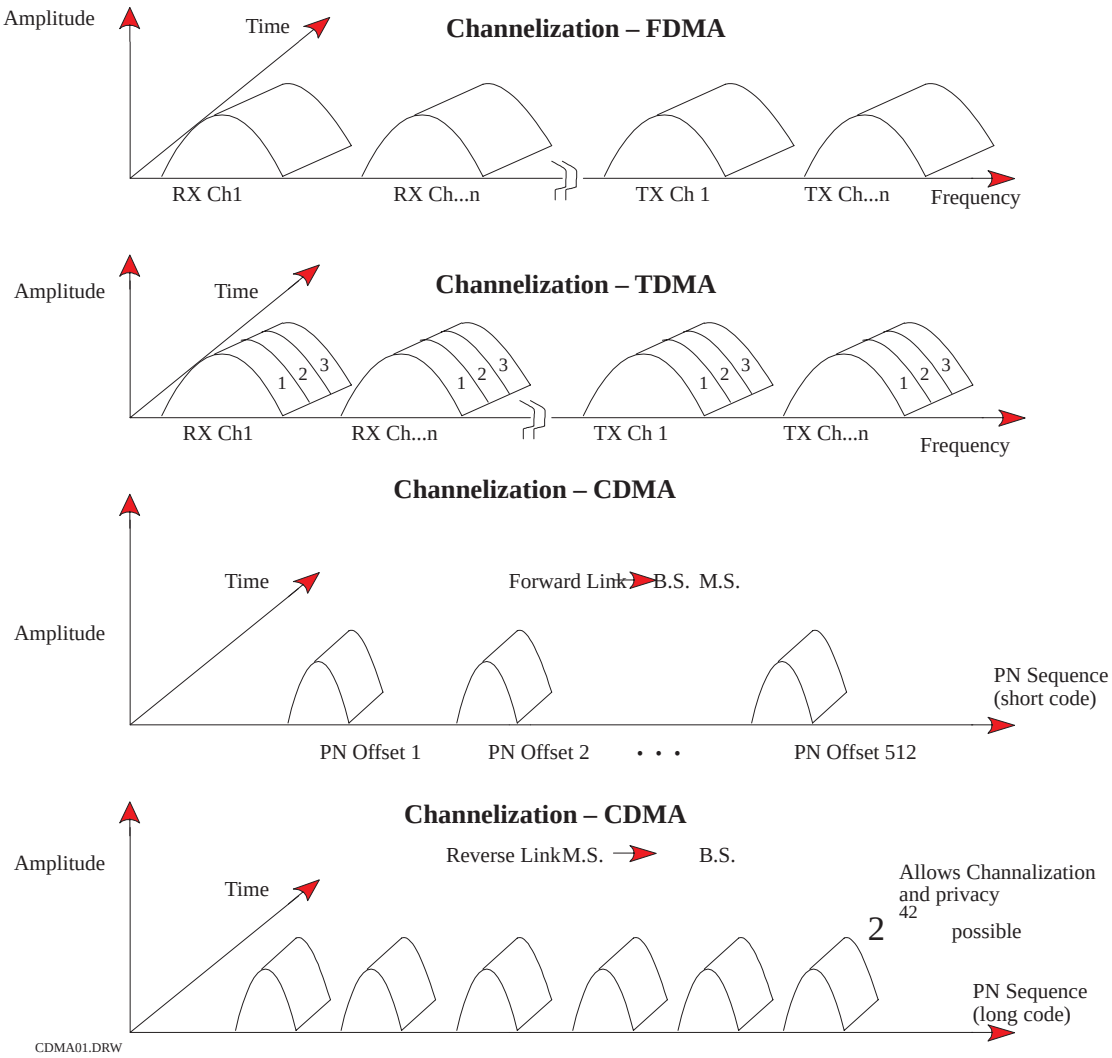

Figure 1. TDMA & CDMA Freq and time domain

With FDMA Channelization (Analog AMPS), a channel is 30 kHz wide, this where all the signal's transmission power is concentrated. Different users are assigned different frequency channels. FDMA is the acronym for Frequency Division Multiple Access. Interference to and from adjacent channels is limited by the use of bandpass filters that only pass signal's within a specified narrow frequency band while rejecting signals at other frequencies. The analog FM cellular system AMPS, uses FDMA.

The US 800 MHz cellular system divides the allocated spectrum into 30 kHz bandwidth channels. Narrowband FM modulation is used with AMPS, resulting in 1 call per 30 kHz of spectrum. Because of interference, the same frequency cannot be used in every cell.

The frequency reuse factor is a number representing how often the same frequency can be reused. To provide acceptable call quality, a Carrier–to–Interference ratio (C/I) of at least 18 dB is needed. Practical results show that in most cases to maintain a 18 dB (C/I) a frequency reuse factor of 7 is required. Please note that C/I is carrier to interference, not signal to noise ratio The resulting capacity is one call per 210 kHz of spectrum in each cell.

With TDMA, a channel consists of a time slot in a periodic train of time intervals making up a frame. A given signal's energy is confined to one of these time slots. The IS–54B TDMA standard provides a basic modulation efficiency of three voice calls per 30 kHz of bandwidth. The resulting capacity is one call per 70 kHz of spectrum or three times that of the analog FM system.

With CDMA each signal consists of a different pseudo random binary sequence that modulates the carrier, spreading the spectrum of the waveform. A large number of CDMA signals share the same frequency spectrum. The signals are separated in the receivers by using a correlator that accepts only signal energy from the selected binary sequence and de–spreads its spectrum simultaneously. The other users' signals, whose codes do not match, are not de–spread and as a result, contribute only minimally to the noise and represent a self–interference generated by the system. The forward link (B.S. to M.S.) "channels" are separated by offsets in the short code PN sequence. Reverse link channels are separated by different long code PN sequences. A detailed description of the forward and reverse links is given later.

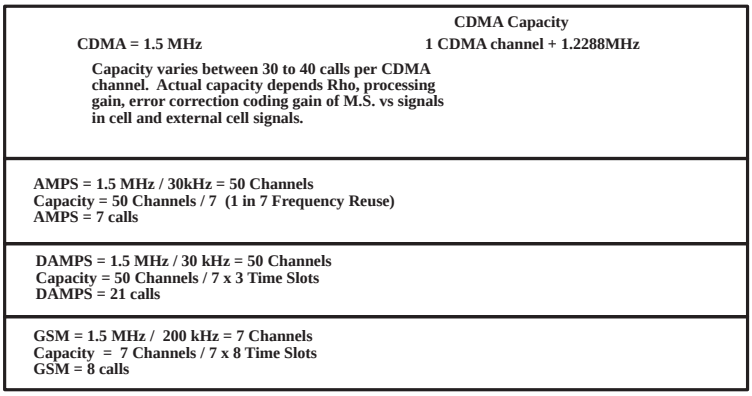
CDMA Capacity
CDMA = 1.5 MHz
1 CDMA channel + 1.2288MHz
Capacity varies between 30 to 40 calls per CDMA channel. Actual capacity depends Rho, processing gain, error correction coding gain of M.S. vs signals in cell and external cell signals.
AMPS = 1.5 MHz / 30kHz = 50 Channels
Capacity = 50 Channels / 7 (1 in 7 Frequency Reuse)
AMPS = 7 calls
DAMPS = 1.5 MHz / 30 kHz = 50 Channels
Capacity = 50 Channels / 7 x 3 Time Slots
DAMPS = 21 calls
GSM = 1.5 MHz / 200 kHz = 7 Channels
Capacity = 7 Channels / 7 x 8 Time Slots
GSM = 8 calls

Figure 2. CDMA Capacity gains

Why should NOKIA go to so much trouble to develop CDMA? **CAPACITY!** To see how CDMA increases capacity over present 800 MHz systems (AMPS and DAMPS) lets look at a 1.5 MHz span of frequencies and compare. A CDMA frequency channel is 1.2288 MHz wide however to provide guard bands in order to reduce potential interference with adjacent analog channels a total of 1.5 MHz will be used.

The AMPS, DAMPS, and GSM capacity examples assume that only one channel out of every seven can be used. In a crowded metropolitan area, cellular base stations are arranged like the top part of Figure 3 Each base station is surrounded by seven others so only one out every 7 channels can be used or adjacent channel interference will occur. However, such is not the case for CDMA because all users on a “CDMA Channel” operate on the same frequency. I’ve just used the word “Channel” in a different way. Users in a given CDMA channel are separated by different PN code sequences. According to information at the present time there four designated CDMA frequency channels, so users on a given frequency channel operate on the same frequency and are separated by different PN code sequences which are also called “Channels”.

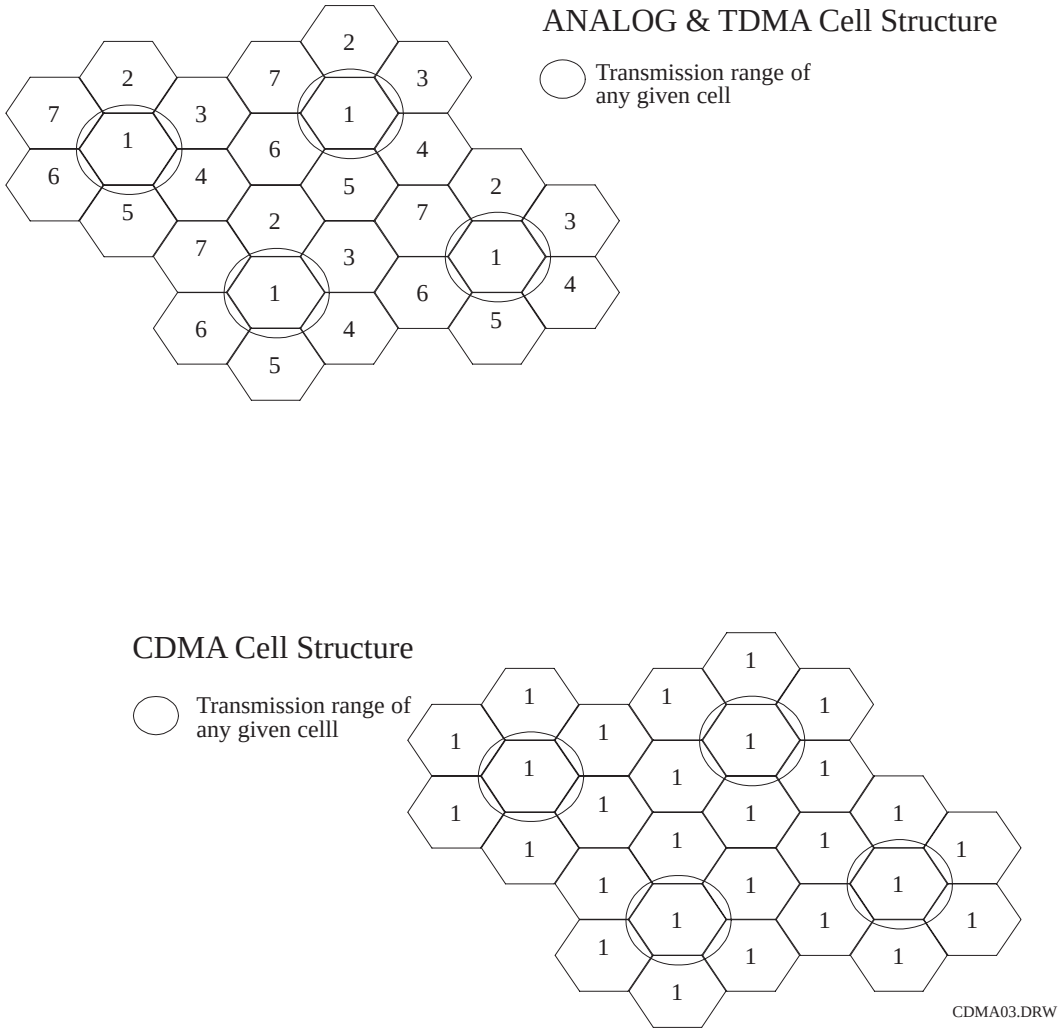
ANALOG & TDMA Cell Structure
Transmission range of any given cell
CDMA Cell Structure
Transmission range of any given celll
CDMA03.DRW

Figure 3. TDMA & CDMA Structure

Quadrature Phase Shift Keying – QPSK

Forward link transmissions from the Base Station (BS) to the Mobile Subscriber (MS) use QPSK modulation. QPSK is the sum of Two Binary Shift Keyed (BPSK) signals. Figure 4 shows how a BPSK signal is made up.

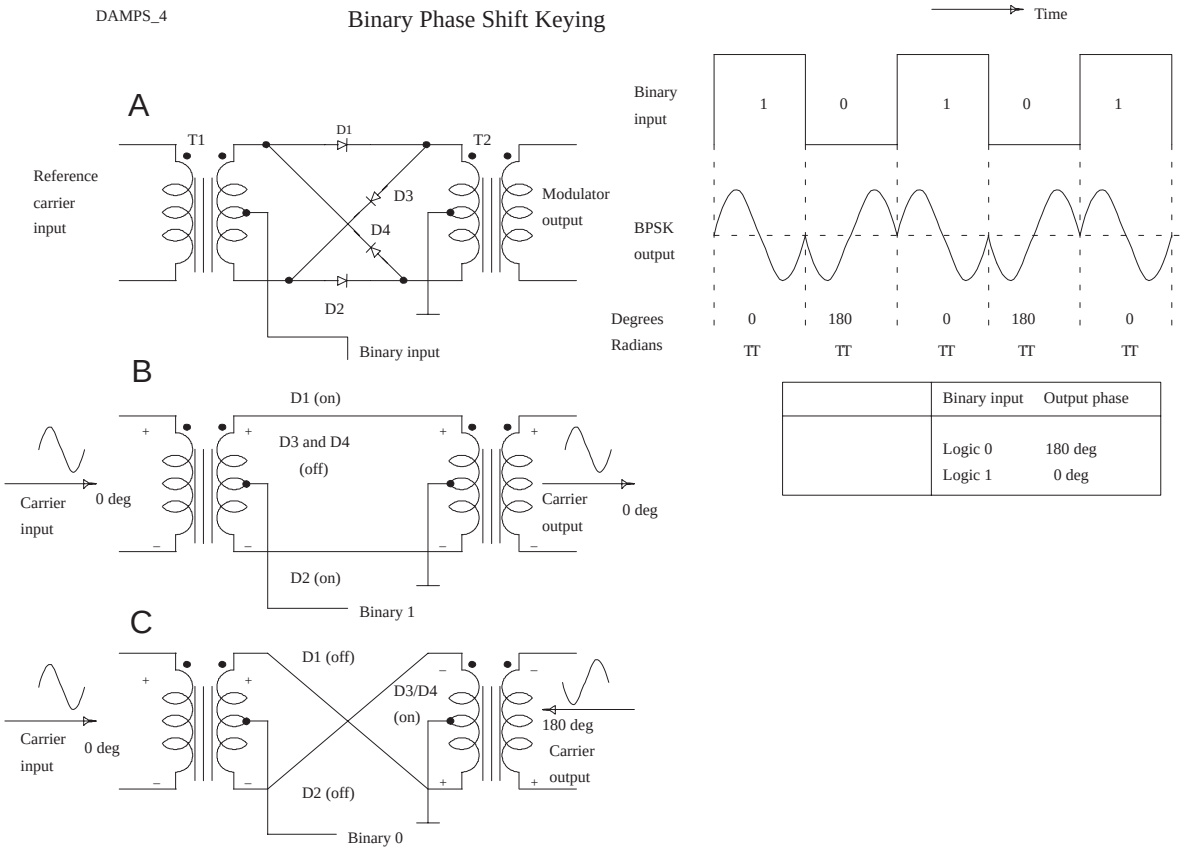

Figure 4. BPSK Modulator

Before starting any explanation about phase modulation a convention needs to be established that will carry on throughout this study guide. **Digital signals are generally generated by use of a modulator that generates a sine and a cosine channel and scales each channel by a factor that ranges from –1 to +1. What the last sentence means is that the values of Data Channels are –1 and +1, not 0 and 1. A logic one will be “plus one” and a logic zero will be “minus one”.**

In drawing ”B” diodes D1 and D2 are forward biased into conduction with a logic one. Transformer’s T1 and T2 are connected together in an in–phase condition. In this case the output carrier’s signal would have the same phase as the input.

In drawing “C”diodes D3 and D4 are forwarded biased into conduction with a logic zero. The output of T1 is cross connected to the input of T2 which will result in the output being 180 degrees out of phase with the input signal.

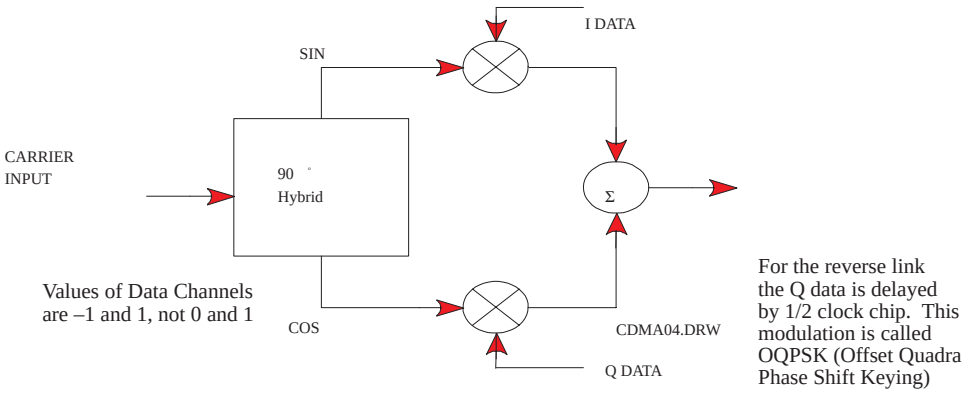

Figure 5. I/Q Modulator

In Figure 5 the 90° phase shifter is used to generate the sine and cosine channel reference frequency. The two signal paths are called the “In phase” and the “Quadrature phase” paths, therefore the name, I/Q modulator.

The CDMA Signal

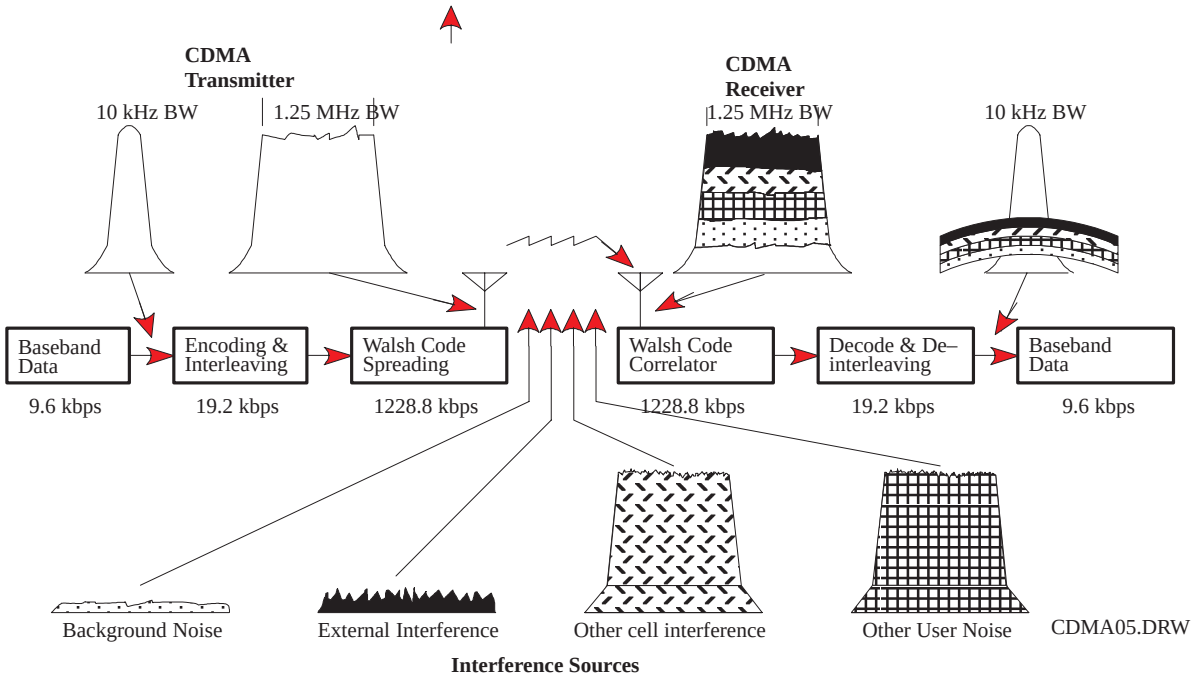

Figure 6. CDMA Waveforms

To explain CDMA, some terms will have to be used that most persons are not familiar with, but have patience they will be given a full explanation later in this Study Guide. Forward link (BS to MS) CDMA starts with a narrowband signal that is digitized speech. In this example the *full rate speech data rate* of 9600 bps is shown.

Speech data rates from the VOCODER can vary from 1200 BPS to 9600 BPS when using “Rate Set One” and 14.4, 7.2, 3.6, and 1.8 kbps when using “Rate Set Two”. A specialized digital code called a Walsh Code provides “user” channelization for the forward link (B.S to M.S.) and is used to encode the reverse link (B.S. to M.S.) user data. The short code PN sequence *SPREADS* the baseband for both forward and reverse links. The short code also provides channelization for BASE STATIONS on the forward link by using a masking circuit. Masking will be explained later.

Processing Gain

One of the unique aspects of IS–95 standard CDMA is 21 dB of processing gain. Processing gain is computed by using the formula 10 log(spread data rate) divided by (Symbol rate). [10 log (1,228,800 / 19.2kBPS) = 21 dB]. If you calculate the processing gain using the numbers in the last sentence the answer is 18 dB. The extra 3 dB is comes from the same data being transmitted by the Q channel. If rate set 2 is used the processing gain is 19.31 dB. When “your” CDMA signal is transmitted all other CDMA signals along with background noise and any spurious signals are considered interference.

When the wanted CDMA signal, “yours”, is received the correlation receiver recovers “your” signal and rejects the rest. Looking at Figure 6, the upper right most part of the drawing shows what happens to the unwanted signals. The unwanted signals are not de–spread so that each interfering signal only contributes a little to the noise floor while “your” wanted signal is de–spread and will have an acceptable signal–to–noise ratio. This is where the processing gain comes into play. The processing gain is 21 dB and it takes a signal–to–noise ratio of about 7 dB for acceptable voice quality. This leaves 14 dB of processing gain to extract “your” signal from the noise.

Here are some of the differences between CDMA and analog FM (AMPS).

Multiple users are on one frequency at the same time. RF engineers have spent a lot of time and effort trying to keep signals on one channel so that adjacent channel signals would not cause interference. CDMA technology places a great many conversations (signals) on the same frequency.

In CDMA a channel is defined by various digital codes in addition to having different frequencies. Analog FM channels are defined by different frequencies only.

An analog FM (AMPS) cell site has a hard limit on the number of users it can accommodate, only one call per frequency channel. CDMA has a soft capacity limit. If cells surrounding a heavily loaded cell are lightly loaded then the heavily loaded cell site can accommodate additional users. CDMA has a soft limit because less “other cell” interference causes the total interference to be less. More calls can also be accommodated at the expense of lower voice quality (S/N), this because each additional user adds only a small amount of interference to the total.

The CDMA Forward Link

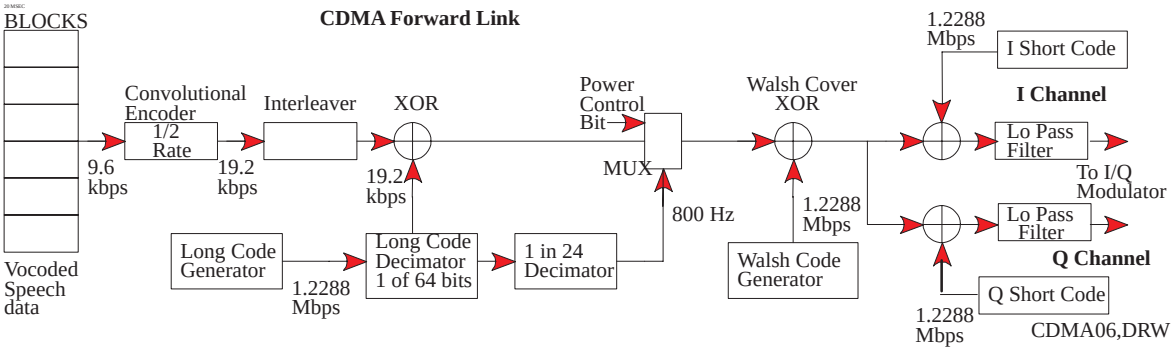

Figure 7. CDMA Forward Link

When discussing the CDMA Forward Link, voice data will be shown at 9600 BPS (full rate). Keep in mind that the Vocoded Speech rate can be 9600, 4800, 2400 or 1200 BPS when using Rate Set One. The Vocoded Speech rate is developed after the CODEC in both the Base Station and the Mobile Phone.

Speech data is passed through a Convolutional Encoder that doubles the data rate. This data is then Interleaved. Interleaving does not change the data rate but will introduce some data time delay. The Long Code Generator running at 1.2288 Mbps develops the 242 bits long PN (Pseudo–random noise) code. The long code Decimator uses one out of every 64 bits of the PN long code and exclusive OR's this decimated bit stream with the output of the Interleaver. At this point the data stream is still running at 19.2 kbps. The 64 bit Walsh Code Generator output running at 1.2288 Mbps is exclusive OR'ed with the pervious exclusive OR gate's output. The baseband is now running at a data rate of 1.2288 Mbps, 64 times 19.2 kbps. The Walsh encoded data stream is then split into I and Q channels, and then each channel is spread with a short code. Then finally, signals are sent through a low pass filter to the I/Q modulators.

Vocoder

CDMA takes advantage of quiet times during speech to raise capacity. A variable rate VOCODER is used; the vocoder's output is at 9600 BPS when the user is speaking. When the user pauses, or is listening, the data rate drops to 1200 BPS. The data rates of 2400 and 4800 BPS are also used but not as often as the other two. The data rate is based on speech activity and complexity. A decision is made on the data rate every 20 msec. Normal speech has about a 40% activity factor. A 40% voice activity factor means that only 40% of transmission time is needed to transmit the intelligible parts of speech.

Convolutional Encoder

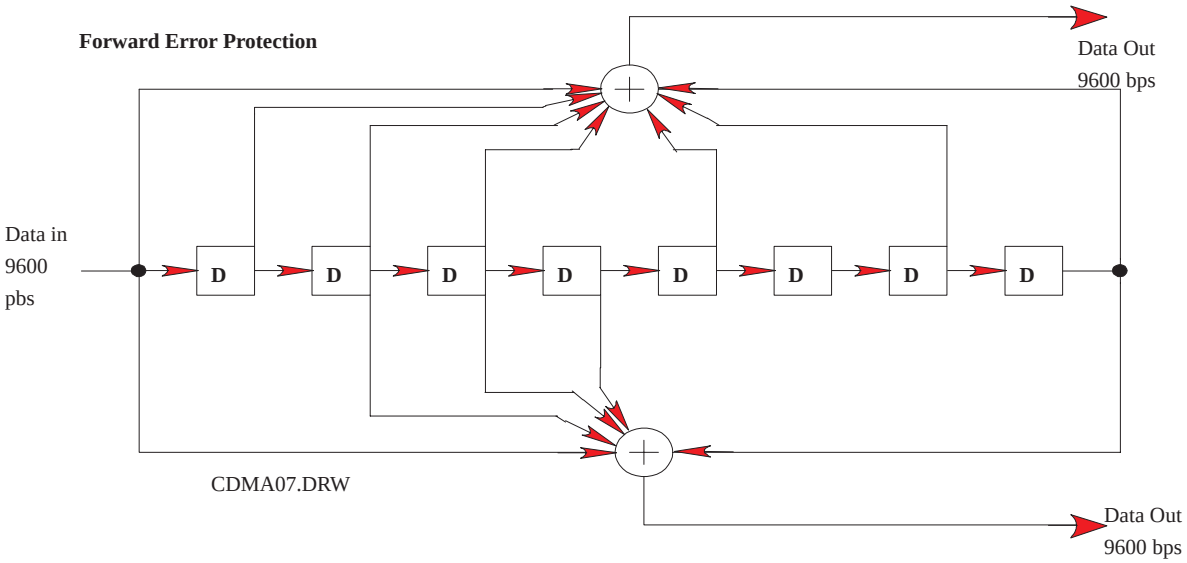

Figure 8. Convolutional encoder

The forward CDMA link uses a half–rate convolutional encoder to provide error correction capabilities. A half–rate encoder produces two output bits for every bit input. This type of encoder accepts incoming serial data and outputs encoded data. A convolutional encoder uses a shift register that contains a history of the bit stream. It starts with all zeros and the data stream is shifted through. The two 9600 BPS output data streams are combined at a higher rate to provide a single 19,200 BPS data stream.

Interleaver

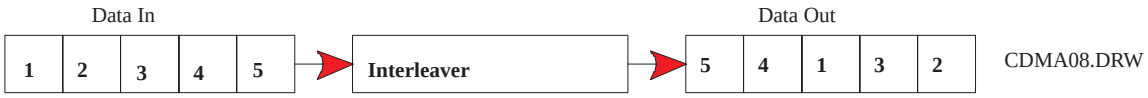

Figure 9. Interleaver

Interleaving is the process of shuffling the data before transmission with a corresponding un–shuffle on the receiving end. The purpose is to spread the bit errors. Bit errors tend to come in bursts due to fading, rather than uniformly spread in time. Interleaving provides a more uniform bit error distribution so that one burst of errors will not wipe out a whole digital word but only individual bits that can be corrected by the convolutional decoding.

PN Code Generation

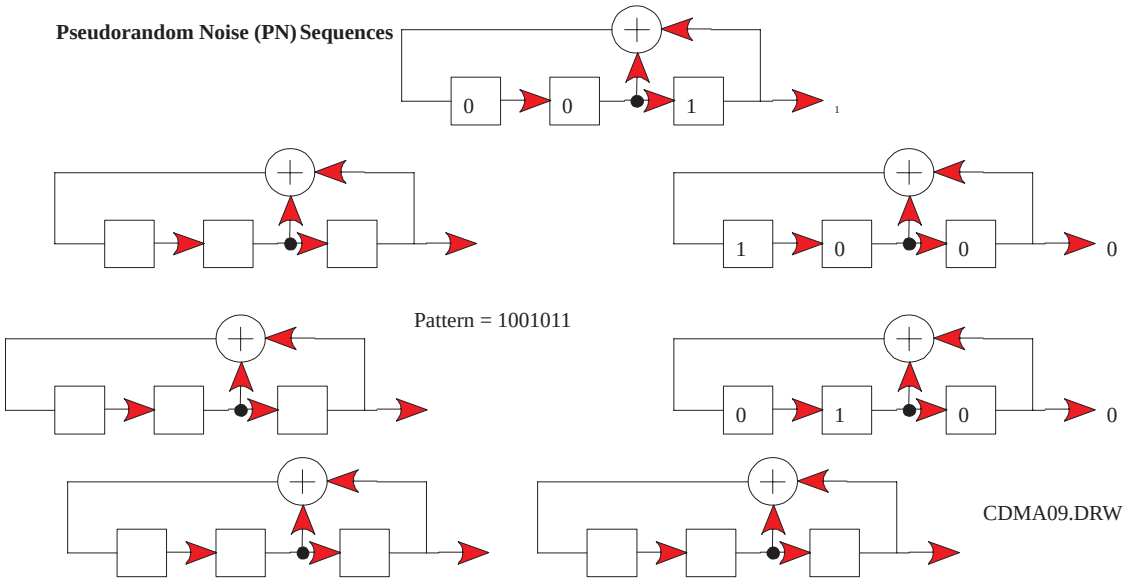

Figure 10. PN Code generator

The illustration above is a highly simplified version of a PN code generator. It will be left to the reader to fill in the blank registers. This generator will start repeating after 7 bits. A CDMA long code register is 42 bits long and the short code register 15 bits long.

The forward link Short Code is the same for all base stations. However a specific mask is AND'ed with the output of the code generator to create a unique short code. Even though the specific mask does not change the PN pattern the code is considered unique relative to system time. This means that each specific mask will shift the PN code to a unique delay with respect to system time and in this way the shifted PN code is considered unique.

Here is another way of saying the same thing: PN codes used are required to have low auto–correlation properties——a time shifted version of itself correlated with itself looks like random noise. Therefore a time shifted version is unique. Short Code and Long Codes are handled the same: they use time shifted versions to be unique.

An example of a mask is shown in Figure 11. The three–bit shift register in Figure 10 has a three–bit mask circuit connected to it in Figure 11.

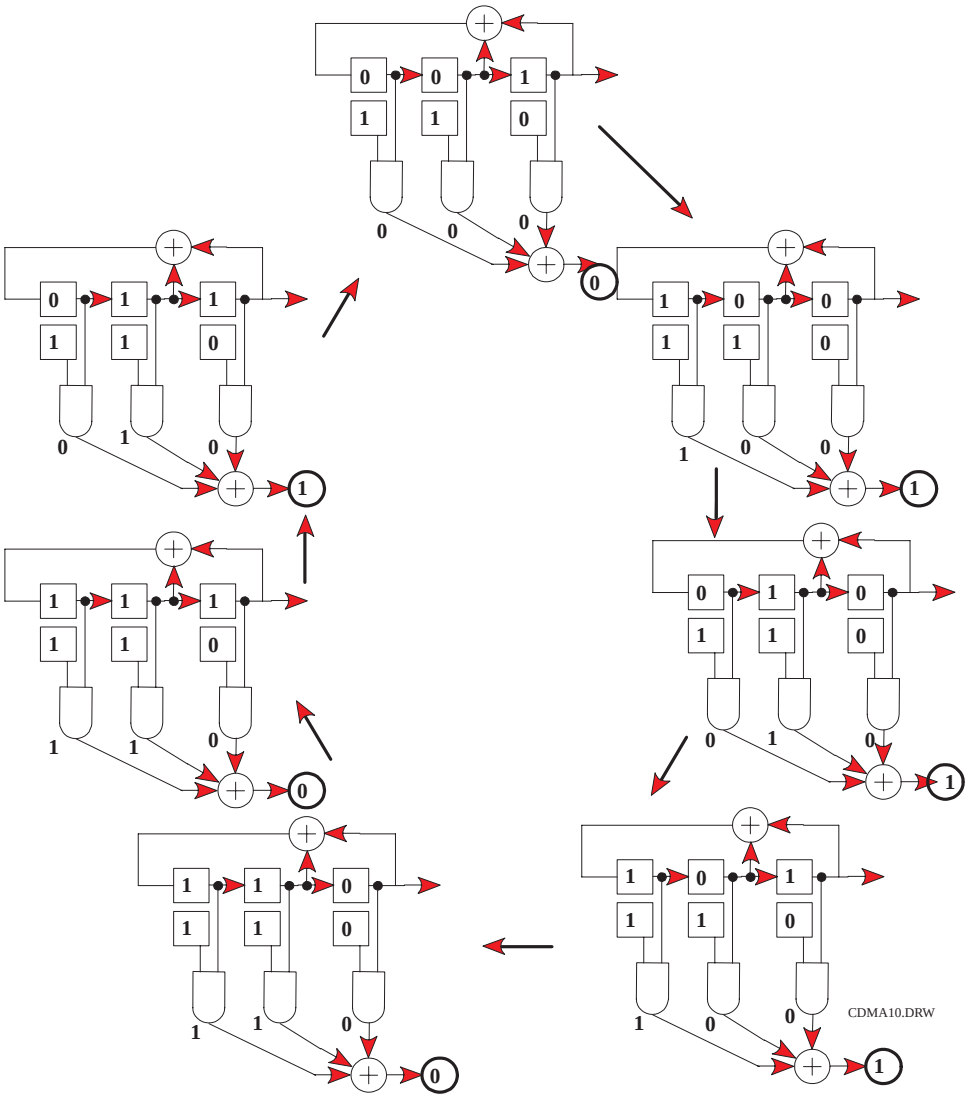

Figure 11. PN Code generator w/mask ckt.

Offset	T0	T1	T2	T3	T4	T5	T6	Base Stations
01	1	0	0	1	0	1	1	1
10	0	0	1	0	1	1	1	2
11	1	0	1	1	1	0	0	3
100	0	1	0	1	1	1	0	4
101	1	1	0	0	1	0	1	5
110	0	1	1	1	0	0	1	6
1111	1	1	1	0	0	1	0	7

Figure 12. Mask offset example

The above example shows how different offsets will create different codes. Note that none of the codes has been altered. Each one just starts at a different time. Remember the CDMA system uses the same 15 bit linear feedback shift register to generate the PN short code for both forward and reverse links. If figure 28 were expanded to a 15–bit shift register the time shifted short codes for the 512 base station channels would be shown.

Long Code Scrambling

In the forward link the long code is used to scramble voice data and provide some measure of security. However the complete long code is not used, refer to Figure 28. A Long Code Decimator allows only one in every 64 bits of the Long Code to be exclusively OR'ed with the Encoded Voice Data. This scrambling does not increase the data rate because two 19.2 kbps data streams are being exclusive OR'ed with each other.

Walsh Code User Channelization

The CDMA forward link figure will be repeated here to show where we are in the CDMA forward link (base station to mobile) generation.

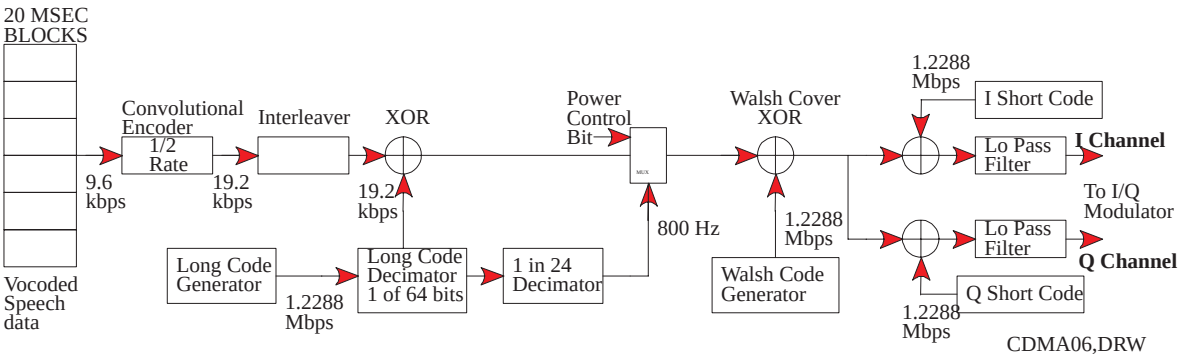

Figure 13. CDMA Forward Link

The 20 msec VOCODED speech data blocks have had an error correction routine added in the Convolutional Encoder that increased the data rate to 19.2 ksps (kilo symbols per second).

The Interleaver changes the data order so only bits instead of whole words would be lost because of data errors. The Long Code Generator generates a code that is 242 bits long. This code runs at 1.2288 Mbps and takes about 41.5 days before it repeats. The PN (Pseudo–random) code is decimated by a factor of 64 that means only one out of 64 bits is XOR'ed with the output of the Interleaver. The data rate at this point is still 19.2 ksps because two 19.2 ksps data streams have been XOR'ed.

The 64 Walsh codes are used in the forward link as a means to uniquely identify each user. The Walsh code generator runs at 1.2288 Mbps while the encoded voice data runs at 19.2 kbps the ratio is 64 or 21 dB of processing gain. This means that each data bit is XOR'ed with 64 Walsh code bits, one complete 64 bit Walsh code. The voice data determines the polarity of the Walsh code. This makes it easier for the CDMA mobile to find and decode its assigned Walsh code. All base station's use the same Walsh code 64 set. What gives each base station its own unique identity will be explained in "Short Code Spreading"

The forward link is now running at its final rate of 1.2288 Mbps.

Walsh Codes

Walsh Codes in the CDMA forward link are used to "make" the CDMA forward channels. Remember in analog phones a different frequency channel is used to separate one cell phone user from another. TDMA cell phones use different time slots to allow 3 phones to share one frequency channel. CDMA uses different frequency channels like analog and TDMA cell phones. However, to separate CDMA users on the same base station, different codes are used on the forward link (Base Station to Mobile). IS–95 Standard CDMA uses Walsh code set 64. This Walsh set has 64 unique codes each having 64 bits. Figure 14 shows how a Walsh code set is built up.

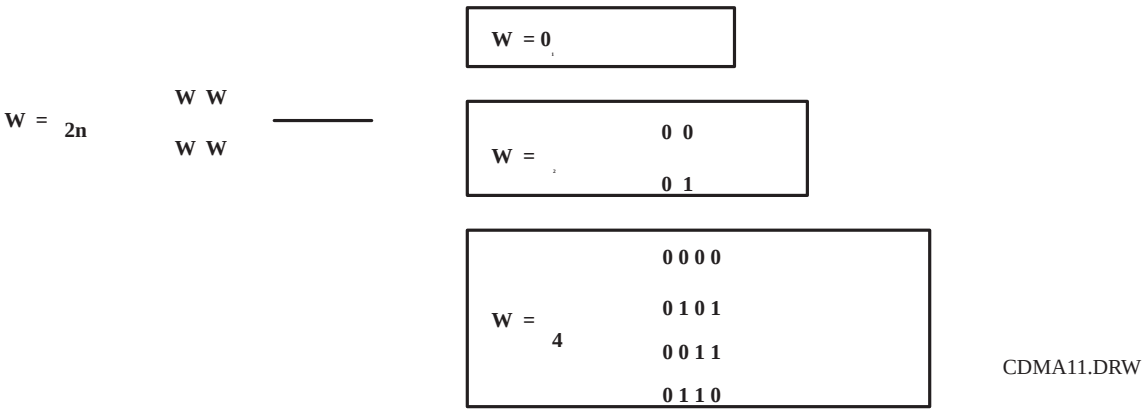

Figure 14. Walsh code example

Walsh code sets are generated by using the formula W2n = W W

W W .

In Walsh code set 2 it can be seen that the lower right digit is the logical not of the other three digits. In Walsh code 4 the set 2 code is repeated three times with the logical not being used in the lower right corner. The expansion number is always a power of 2 and also notice that for each set the first code is always all zeros.

Walsh codes have the desirable characteristic of being “orthogonal” to each other. What the heck does that mean(this is a rhetorical question)? ORTHOGONAL Walsh Codes: when simultaneously transmitted they produce minimal interference to other users. Look at the rows across in code set 4, any two rows have an equal number of matches and mismatches. When correlation occurs between codes (they match up) they will yield a cross correlation coefficient of 1. When the codes do not match (correlate) the cross correlation coefficient is 0. Another way of stating this is to say that when receiving the desired code a correlation receiver will yield data and ignore all the unwanted codes.

Figure 15 should help sort out how Walsh orthogonal codes can keep different CDMA users separated even though they are on the same frequency.

Orthogonal Functions

Two values are orthogonal if the result of exclusive–ORing them results in an equal number of 1’s and 0’s.

Figure 15. uses the number 2 code, 0 1 0 1, in the Walsh code set 4 to “Orthogonally Spread” some user input data. Each bit of user input data is exclusive–OR’ed with the number 2 Walsh code that will result in TX Data shown in Figure 15.

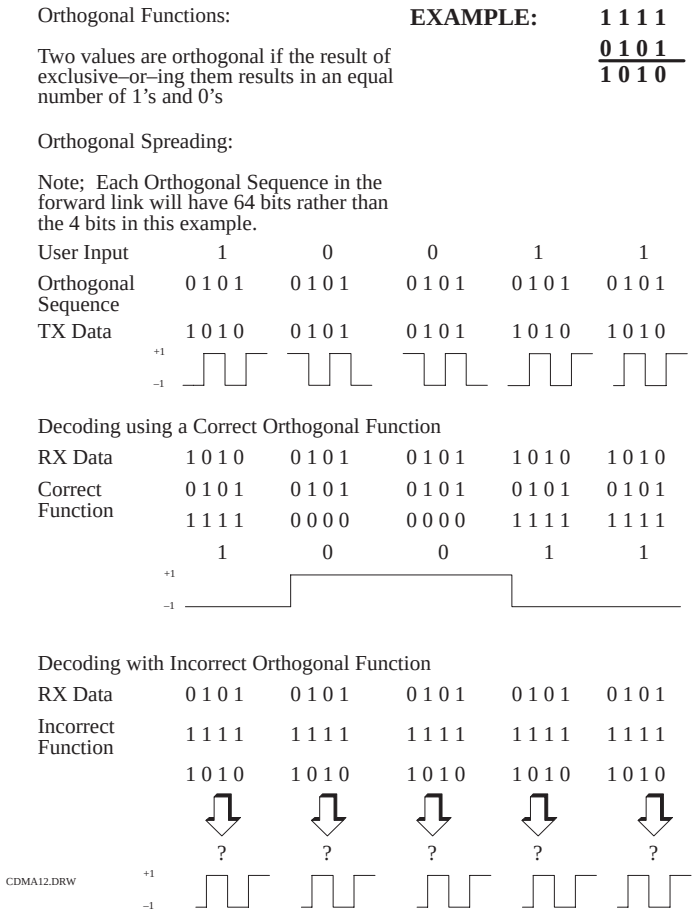
Orthogonal Functions:
Two values are orthogonal if the result of exclusive–or–ing them results in an equal number of 1’s and 0’s
EXAMPLE:
1 1 1 1
0 1 0 1
1 0 1 0
Orthogonal Spreading:
Note; Each Orthogonal Sequence in the forward link will have 64 bits rather than the 4 bits in this example.
User Input 1 0 0 1 1
Orthogonal Sequence 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
TX Data 1 0 1 0 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0
+1
–1
Decoding using a Correct Orthogonal Function
RX Data 1 0 1 0 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0
Correct Function 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
1 1 1 1 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1
1 0 0 1 1
+1
–1
Decoding with Incorrect Orthogonal Function
RX Data 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
Incorrect Function 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
? ? ? ? ?
+1
–1
CDMA12.DRW

Figure 15. Orthogonal Functions.

When the number 2 Walsh code is exclusive OR'ed with what is now the "RX data" each number 2 Walsh code yields the original user input data 4 times. The IS–95 CDMA standard uses a 64–bit Walsh code so the mobile cell phone has the transmitted data repeated 64 times. When the data is repeated 64 times, your have processing gain. Repeating the processing gain information: 10 log 64 equals 18 dB: another 3 dB is added because the data is modulated on two channels, I and Q for a total of 21 dB. This is one of the reasons why IS–95 CDMA is so tolerant of noise. That is to say a signal–to–noise ratio that would render an analog signal useless works fine with CDMA.

BUT JUST HOW DOES AN ORTHOGONAL WALSH CODE SEPARATE DIFFERENT USERS?

At first it would seem that broadcasting 25 to 30 code streams on one frequency would create an "electronic tower of babel". To explain how Walsh encoding works a Walsh code set 2 that has 2 orthogonal Walsh codes will be used in Figure 16

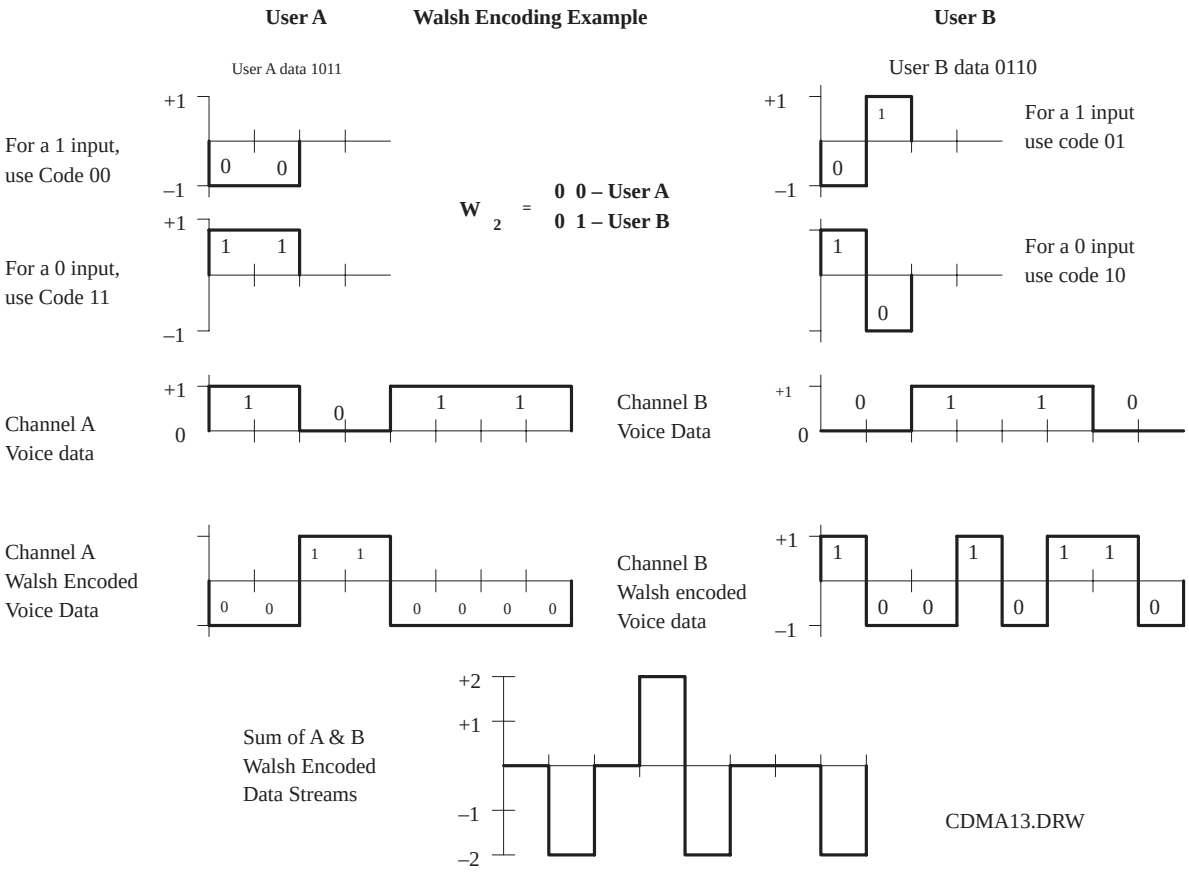
User A
Walsh Encoding Example
User B
User A data 1011
User B data 0110
For a 1 input, use Code 00
For a 0 input, use Code 11
W 2 = 0 0 – User A
0 1 – User B
For a 1 input use code 01
For a 0 input use code 10
Channel A Voice data
Channel B Voice Data
Channel A Walsh Encoded Voice Data
Channel B Walsh encoded Voice data
Sum of A & B Walsh Encoded Data Streams
CDMA13.DRW

Figure 16. Walsh Encoding Example

This example uses Walsh Code set 2 that has two unique orthogonal codes, "00" and "01". Walsh code "00" will be assigned to User A and code "01" to User B. Now in order for the Walsh code addition to work, bipolar values must be used, so that a binary "0" has a value of "–1". Also unless some higher math is utilized one more convention must be used. If the voice data is a "0", User A's Walsh code is "+1,+1".

Here is how the “bipolar” addition works:

Voice data		1	0	1	1
bipolar Walsh code	–1–1	+1+1	–1–1	–1–1	
Walsh encoded data		0 0	1 1	0 0	0 0

The voice data is added to both bipolar Walsh code numbers. The example is for User A.

If the two Walsh encoded voice data channels are added together the result is a data stream that varies between +2 and –2. Walsh code decoding will show that both user data streams are contained in this waveform and further more they do not interfere with each other.

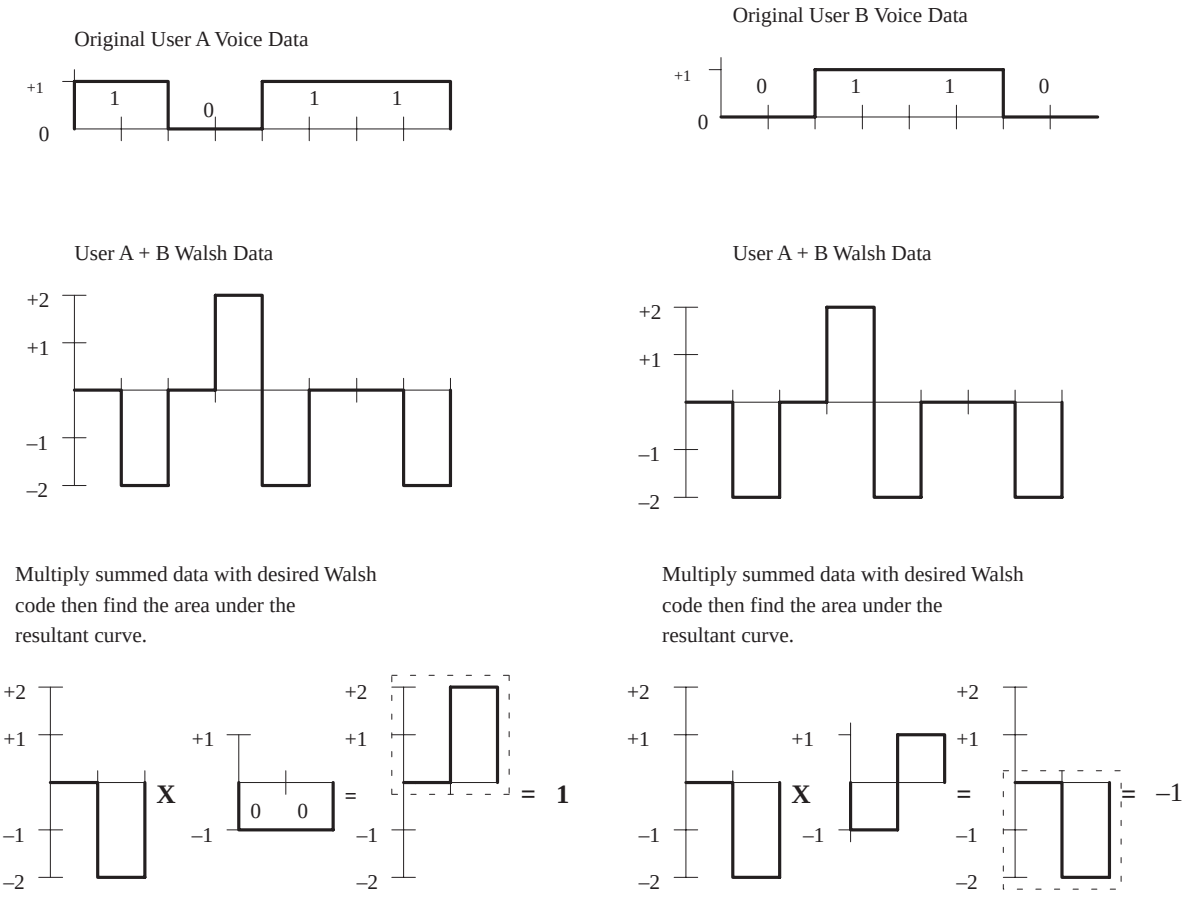
Original User A Voice Data
Original User B Voice Data
User A + B Walsh Data
User A + B Walsh Data
Multiply summed data with desired Walsh code then find the area under the resultant curve.
Multiply summed data with desired Walsh code then find the area under the resultant curve.
CDMA14.DRW

Figure 17. Walsh Decoding Example

To see how user data is recovered from the summed signal lets extract the first bit of each users’ data. First remember that each user bit is XOR’ed with two Walsh code bits in this example. Taking the first two summed data bits, multiply them with desired Walsh code. For User A this results in a wave form that starts at zero for the first bit period and goes to +2 in the second bit period, 0 X –1 = 0 and –2 X –1 = +2. The next step requires a little calculus, very little to figure “the area under the curve”. Since the waveform is a square wave its not to hard. Add the two resultant bits and divide by the number of bit periods, (0 + 2) / 2 = 1. User A’s first data bit is “1”.

To calculate User B's first data bit multiply (0 X –1) and (–2 X 1) which equals zero, minus two waveform. Find the area under the curve, (0 + (–2)) / 2 = –1, which is User B's first data bit.

It has been stated that Walsh codes are orthogonal and that this property results in zero cross talk between Walsh code signals. Using bipolar numbers multiply Walsh code "00" with Walsh code "01". Add the resulting area and divide by the number of bit periods and you will get zero. Figure 18 illustrates this.

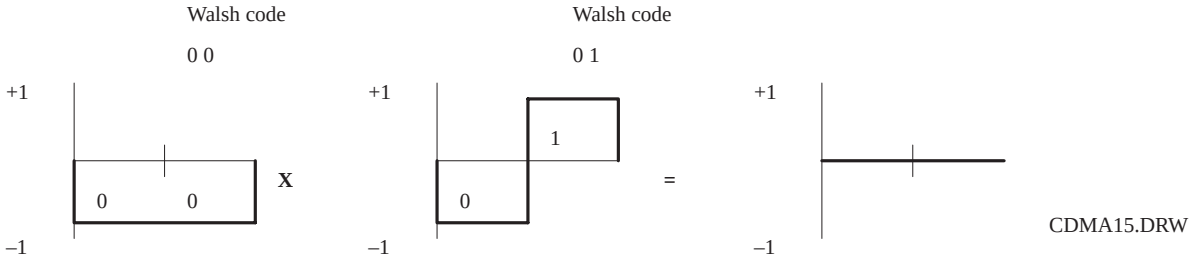

Figure 18. Definition of orthonogonality

Another and simpler way to state that Walsh codes are orthogonal is that since the codes have an equal number of matches and mismatches, they are orthogonal.

The full 64–bit by 64 code Walsh code set 64 has been reproduced in the following table.

Walsh Code Set W64

0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
1	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01
3	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01	01
	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110
	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110
4	00	111	00	111	00	111	00	111	00	111	00	111	00	111	00	111
5	00	110	00	110	00	110	00	110	00	110	00	110	00	110	00	110
6	01	10	01	10	01	10	01	10	01	10	01	10	01	10	01	10
7	01	110	01	110	01	110	01	110	01	110	01	110	01	110	01	110
	00	01	00	01	00	01	00	01	00	01	00	01	00	01	00	01
	110	00	110	00	110	00	110	00	110	00	110	00	110	00	110	00
	110	1	110	1	110	1	110	1	110	1	110	1	110	1	110	1
8	00	00	111	111	00	00	111	111	00	00	111	111	00	00	111	111
9	00	00	110	110	00	00	110	110	00	00	110	110	00	00	110	110
1	01	01	10	10	01	01	10	10	01	01	10	10	01	01	10	10
0	01	01	110	110	01	01	110	110	01	01	110	110	01	01	110	110
1	00	00	01	01	00	00	01	01	00	00	01	01	00	00	01	01
1	110	110	00	00	110	110	00	00	110	110	00	00	110	110	00	00
	110	110	1	1	110	110	1	1	110	110	1	1	110	110	1	1

1	00	111	111	00	00	111	111	00	00	111	111	00	00	111	111	00
2	00	110	110	00	00	110	110	00	00	110	110	00	00	110	110	00
1	01	10	10	01	01	10	10	01	01	10	10	01	01	10	10	01
3	01	110	110	01	01	110	110	01	01	110	110	01	01	110	110	01
1	00	01	01	00	00	01	01	00	00	01	01	00	00	01	01	00
4	110	00	00	110	110	00	00	110	110	00	00	110	110	00	00	110
1	110	1	1	110	110	1	1	110	110	1	1	110	110	1	1	110
5																
1	00	00	00	00	111	111	111	111	00	00	00	00	111	111	111	111
6	00	00	00	00	110	110	110	110	00	00	00	00	110	110	110	110
1	01	01	01	01	10	10	10	10	01	01	01	01	10	10	10	10
7	01	01	01	01	110	110	110	110	01	01	01	01	110	110	110	110
1	00	00	00	00	01	01	01	01	00	00	00	00	01	01	01	01
8	110	110	110	110	00	00	00	00	110	110	110	110	00	00	00	00
1	110	110	110	110	1	1	1	1	110	110	110	110	1	1	1	1
9																
2	00	111	00	111	111	00	111	00	00	111	00	111	111	00	111	00
0	00	110	00	110	110	00	110	00	00	110	00	110	110	00	110	00
2	01	10	01	10	10	01	10	01	01	10	01	10	10	01	10	01
1	01	110	01	110	110	01	110	01	01	110	01	110	110	01	110	01
2	00	01	00	01	01	00	01	00	00	01	00	01	01	00	01	00
2	110	00	110	00	00	110	00	110	110	00	110	00	00	110	00	110
2	110	1	110	1	1	110	1	110	110	1	110	1	1	110	1	110
3																
2	00	00	111	111	111	111	00	00	00	00	111	111	111	111	00	00
4	00	00	110	110	110	110	00	00	00	00	110	110	110	110	00	00
2	01	01	10	10	10	10	01	01	01	01	10	10	10	10	01	01
5	01	01	110	110	110	110	01	01	01	01	110	110	110	110	01	01
2	00	00	01	01	01	01	00	00	00	00	01	01	01	01	00	00
6	110	110	00	00	00	00	110	110	110	110	00	00	00	00	110	110
2	110	110	1	1	1	1	110	110	110	110	1	1	1	1	110	110
7																
2	00	111	111	00	111	00	00	111	00	111	111	00	111	00	00	111
8	00	110	110	00	110	00	00	110	00	110	110	00	110	00	00	110
2	01	10	10	01	10	01	01	10	01	10	10	01	10	01	01	10
9	01	110	110	01	110	01	01	110	01	110	110	01	110	01	01	110
3	00	01	01	00	01	00	00	01	00	01	01	00	01	00	00	01
0	110	00	00	110	00	110	110	00	110	00	00	110	00	110	110	00
3	110	1	1	110	1	110	110	1	110	1	1	110	1	110	110	1
1																

3 00 00 00 00 00 00 00 00 111 111 111 111 111 111 111 111
2 00 00 00 00 00 00 00 00 110 110 110 110 110 110 110 110
3 01 01 01 01 01 01 01 01 10 10 10 10 10 10 10 10
3 01 01 01 01 01 01 01 01 110 110 110 110 110 110 110 110
3 00 00 00 00 00 00 00 00 01 01 01 01 01 01 01 01
4 110 110 110 110 110 110 110 110 00 00 00 00 00 00 00 00
3 110 110 110 110 110 110 110 110 1 1 1 1 1 1 1 1
5

3 00 111 00 111 00 111 00 111 111 00 111 00 111 00 111 00
6 00 110 00 110 00 110 00 110 110 00 110 00 110 00 110 00
3 01 10 01 10 01 10 01 10 10 01 10 01 10 01 10 01
7 01 110 01 110 01 110 01 110 110 01 110 01 110 01 110 01
3 00 01 00 01 00 01 00 01 01 00 01 00 01 00 01 00
8 110 00 110 00 110 00 110 00 00 110 00 110 00 110 00 110
3 110 1 110 1 110 1 110 1 1 110 1 110 1 110 1 110
9

4 00 00 111 111 00 00 111 111 111 111 00 00 111 111 00 00
0 00 00 110 110 00 00 110 110 110 110 00 00 110 110 00 00
4 01 01 10 10 01 01 10 10 10 10 01 01 10 10 01 01
1 01 01 110 110 01 01 110 110 110 110 01 01 110 110 01 01
4 00 00 01 01 00 00 01 01 01 01 00 00 01 01 00 00
2 110 110 00 00 110 110 00 00 00 00 110 110 00 00 110 110
4 110 110 1 1 110 110 1 1 1 1 110 110 1 1 110 110
3

4 00 111 111 00 00 111 111 00 111 00 00 111 111 00 00 111
4 00 110 110 00 00 110 110 00 110 00 00 110 110 00 00 110
4 01 10 10 01 01 10 10 01 10 01 01 10 10 01 01 10
5 01 110 110 01 01 110 110 01 110 01 01 110 110 01 01 110
4 00 01 01 00 00 01 01 00 01 00 00 01 01 00 00 01
6 110 00 00 110 110 00 00 110 00 110 110 00 00 110 110 00
4 110 1 1 110 110 1 1 110 1 110 110 1 1 110 110 1
7

4 00 00 00 00 111 111 111 111 111 111 111 111 00 00 00 00
8 00 00 00 00 110 110 110 110 110 110 110 110 00 00 00 00
4 01 01 01 01 10 10 10 10 10 10 10 10 01 01 01 01
9 01 01 01 01 110 110 110 110 110 110 110 110 01 01 01 01
5 00 00 00 00 01 01 01 01 01 01 01 01 00 00 00 00
0 110 110 110 110 00 00 00 00 00 00 00 00 110 110 110 110
5 110 110 110 110 1 1 1 1 1 1 1 1 110 110 110 110
1

5	00	111	00	111	111	00	111	00	111	00	111	00	00	111	00	111
2	00	110	00	110	110	00	110	00	110	00	110	00	00	110	00	110
5	01	10	01	10	10	01	10	01	10	01	10	01	01	10	01	10
3	01	110	01	110	110	01	110	01	110	01	110	01	01	110	01	110
5	00	01	00	01	01	00	01	00	01	00	01	00	00	01	00	01
4	110	00	110	00	00	110	00	110	00	110	00	110	110	00	110	00
5	110	1	110	1	1	110	1	110	1	110	1	110	110	1	110	1
5																
5	00	00	111	111	111	111	00	00	111	111	00	00	00	00	111	111
6	00	00	110	110	110	110	00	00	110	110	00	00	00	00	110	110
5	01	01	10	10	10	10	01	01	10	10	01	01	01	01	10	10
7	01	01	110	110	110	110	01	01	110	110	01	01	01	01	110	110
5	00	00	01	01	01	01	00	00	01	01	00	00	00	00	01	01
8	110	110	00	00	00	00	110	110	00	00	110	110	110	110	00	00
5	110	110	1	1	1	1	110	110	1	1	110	110	110	110	1	1
9																
6	00	111	111	00	111	00	00	111	111	00	00	111	00	111	111	00
0	00	110	110	00	110	00	00	110	110	00	00	110	00	110	110	00
6	01	10	10	01	10	01	01	10	10	01	01	10	01	10	10	01
1	01	110	110	01	110	01	01	110	110	01	01	110	01	110	110	01
6	00	01	01	00	01	00	00	01	01	00	00	01	00	01	01	00
2	110	00	00	110	00	110	110	00	00	110	110	00	110	00	00	110
6	110	1	1	110	1	110	110	1	1	110	110	1	110	1	1	110
3																

Short Code Spreading

The Forward Channel is spread one–more–time. The final spreading uses a Short Code that is 215 (32,768) bits long, runs at 1.2288 Mbps and repeats every 26.667 msec. As previously stated all base stations use the same set of Walsh codes, a short code combined with an “offset” mask allows each base station to have a unique identification. These “PN Offsets” are separated by multiples of sixty–four 1.2288 Mbps clock chips which allows 512 unique time offsets for base station identification (32768 bits / 64 bits = 512 offsets). By XOR’ing the Walsh encoded channels with the offset short code, each base station can reuse all 64 Walsh codes and be uniquely identified from other adjacent cells using the same CDMA frequency channel.

Forward Link Channel Format

First of all remember the word “Channel” means a different “PN Code Sequence” and not a different frequency for this part of the discussion.

A base station transmitter signal is a composite of at least 4 and as many as 42 different channels depending on interference and the Rho of the mobiles. Rho is a figure of merit for specifying: percentage of transmitted power that correlates to the ideal code.

The “Pilot Channel” can be compared with the control channels used in analog. The “Pilot Channel” is unmodulated Walsh code zero spread with Short Code that has a unique mask applied in order for mobiles to identify cells from each other. Pilot channel power is the strongest channel from the base station, with about 20% of the total output power. The Pilot Channel provides the mobile with an easy to demodulate strong signal that is used as a time reference.

The “Sync Channel” transmits timing information and always uses Walsh code 32 which is half zero’s and half one’s. The most important timing information contains the state of the long code feedback shift registers 320 milli–seconds in the future. The mobile can load this information into its long code generator, and start the generator at the proper time. Long code state information is not all that is sent by the sync channel but is one of the more important data.

The “Paging Channel” is the forward links digital control channel. Quite a lot of information is sent to the mobile on this channel, a more complete discussion of all four channels will be given in the section on how a CDMA mobile operates. The first paging channel is always Walsh code one. If more paging channels are needed Walsh codes 2 through 7 can be used.

The “Traffic Channel” is the same thing as an analog voice channel. This is where conversations take place. At least 55 Walsh codes are available for use as traffic channels but the actual number that can be used is around 30 at present.

When all the various channels have been Walsh modulated they are split into I and Q channels which are re–spread with the short code to provide base station identity, filtered to reduce bandwidth and converted to analog signals. The analog I and Q signals from all the channels are summed together and sent to the I/Q modulator for modulation onto an RF carrier.

Figure 19, “Forward Link Channel Format “shows how the various channels are made up.

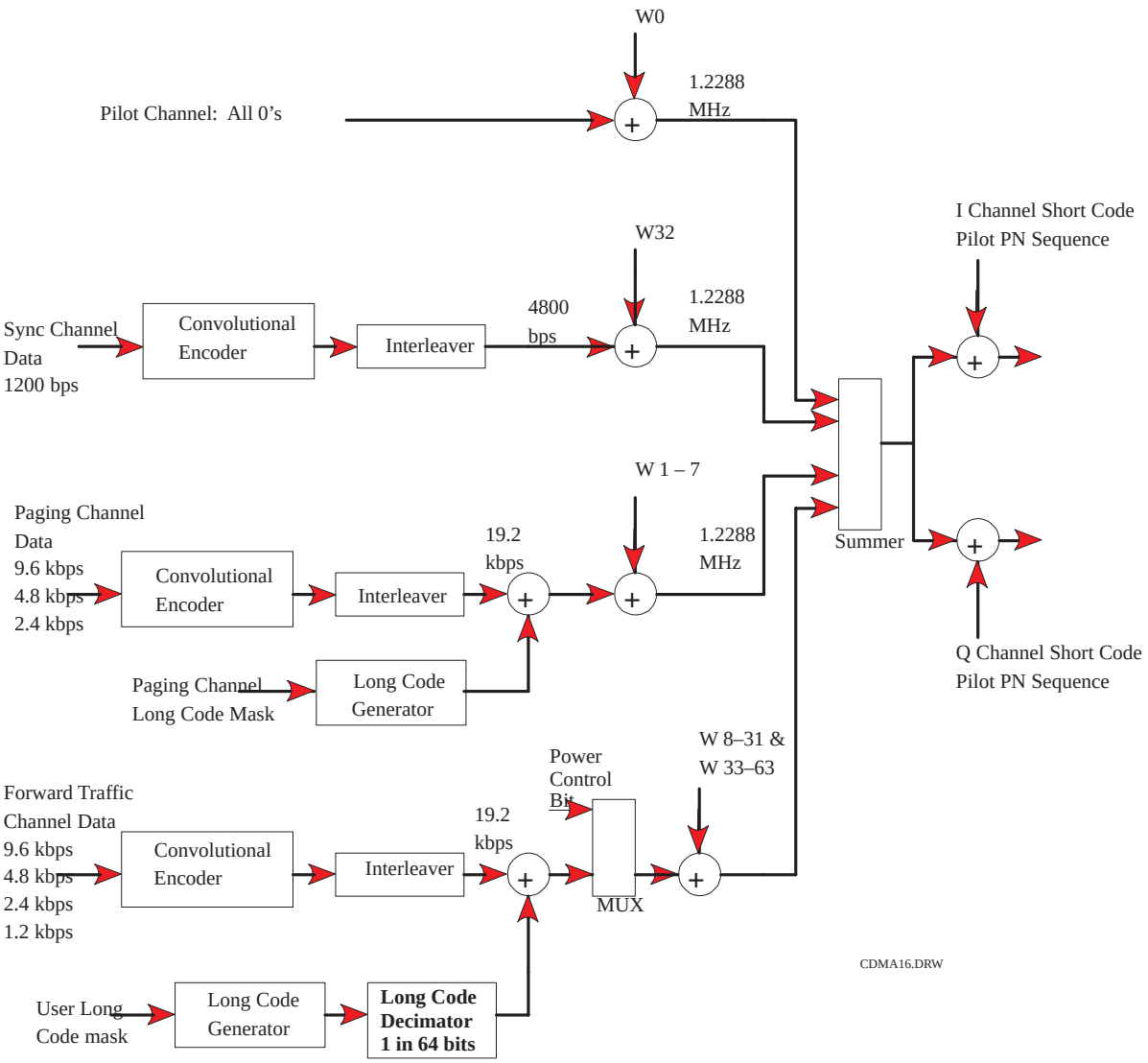

Figure 19. Forward Link Channel Format

CDMA Reverse Link

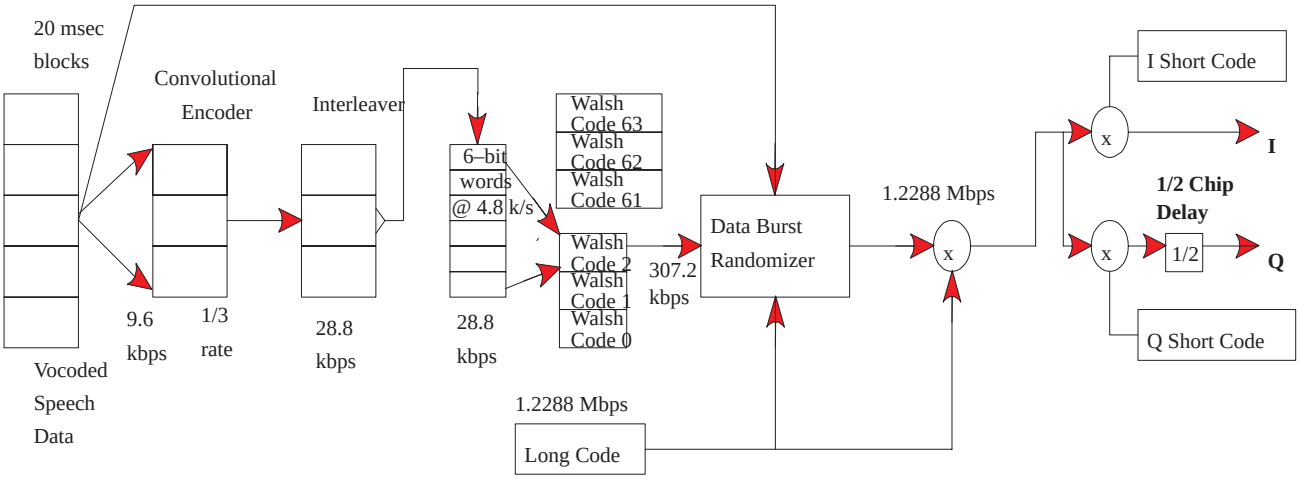

Figure 20. CDMA Reverse Link

The CDMA reverse link (Mobile to Base Station) is quite a bit different from the forward link. The mobile does not have a pilot channel. This is because each phone would have to have its own unique pilot channel and there are only 64 Walsh codes, also the pilot channel power requirements would be severe for the mobile. Because of the lack of a pilot channel and OQPSK (Offset Quadraphase Shift Keyed) modulation the base station will have a tougher time demodulating the mobiles signal. To give the reverse link better performance, a one–third rate Convolutional Encoder is used and six data bits at a time is used to point at one of the 64 Walsh codes. The last sentence will be explained shortly. The 307.2 kbps data is XOR'ed with a long code that is unique for each CDMA cellular phone creating a 1.2288 Mbps data stream. Finally, just like a base station the 1.2288 Mbps data stream is split and XOR'ed with an I & Q short code. The mobile cell phone has one more process, the Q Channel is delayed by one–half clock period.

Data Burst Randomizer

When the vocoder lowers its data rate, the mobile starts turning off its transmitter. At the lowest data rate the mobile transmitter is only on one–eighth of the time. The average output power will drop 3 dB each time the data rate is cut in half. Average output power drops because the mobile's transmit time is cut in half, the peak output power does not change. Now if all the mobiles transmitted at the same time there would not be any reduction of interference. The Data Burst Randomizer randomizes the mobiles transmit time to keep them from transmitting at the same time. Randomizing instructions come from the Frame Rate determination algorithm and the Long Code state in the previous frame.

Reverse Link Error Protection

To improve the reverse link performance a one–third rate convolutional encoder is used. This encoder has one 9600 bps input and three 9600 bps outputs which when combined result in a 28.8 kbps data stream. Each data bit is encoded with 3 error correction bits to improve the error correction rate. The forward link uses one–half rate encoding.

64–ary Modulation

Remember that Walsh codes are orthogonal with each other, which means that several can be broadcast on one frequency without interfering with each other. The mobile does not XOR voice data with a Walsh code. Every six–bits of voice data is used to select one of the 64 Walsh codes. 26 = 64, when six bits of voice data “1 0 1 1 0 1” for example, are converted to a base 10 number it equals 45. So instead of XOR’ing “1 0 1 1 0 1” with one Walsh code, Walsh code 45 represents the six data bits. Again the reason for using Walsh codes is because they are orthogonal with each other, they do not interfere with each other. The six–bit words have a rate of 4800 words per second that means that 4800 64–bit Walsh codes are selected each second. This works out to a data rate of 307.2 kbps.

Reverse Channel Long Code Spreading

The long code shift register is 42 bits long, runs at a rate of 1.2288 Mbps, and repeats it’s self approximately once every 41.5 days. Mobile cellular phones use one of the 4.3 billion long codes for their reverse link channel, each mobile has its own long code. The long codes are uncorrelated, which means they are all different, but they are not orthogonal with each other. Not being orthogonal is a draw–back but the base station knows when the mobiles long code started plus or minus doppler and range uncertainty and this helps with correlation. High speed searcher circuits in the base station allow a quick search over a wide range to lock on a particular user’s signal. The long code at 1.2288 Mbps is XOR’ed with the 307.2 kbps data stream to create a 1.2288 Mbps data rate.

Reverse Channel Short Code Spreading

CDMA mobile phones use the same PN short code sequence as the base station’s use, however the PN code’s purpose is different. The mobile’s use OQPSK (Offset Quadraphase Shift Keyed). OQPSK is accomplished by adding a half period clock delay to the mobile’s Q channel. OQPSK prevents the signal from going to zero magnitude and greatly reduces the dynamic range of the modulated signal. Less costly amplifiers can be used on CDMA mobiles because of the reduced linear dynamic range obtained with OQPSK modulation. The mobile’s short code is not delayed with a mask like the base stations short code is.

Mobile Phone Operation

When a CDMA mobile scans for the strongest Pilot Channel signal, the scanning is done in time rather than frequency scanning like an analog phone does. Once the strongest Pilot channel has been located, Sync Channel information is demodulated. The sync channel contains information the mobile needs in order to decode the Paging Channel. The Paging channel's use can be compared to a digital control channel for DAMPS phones When the mobile goes into a call a Traffic Channel is used.

Pilot Channel

The Pilot Channel is transmitted continuously by the base station to provide mobiles with pilot and sync channel timing. The only modulation on the Pilot Channel is Walsh code zero XOR'ed with the Short Code The Short Code is 215, (32768) bits long and at 1.2288 Mbps takes 26.67 msec before repeating its self. The start time of any base station pilot channel is always an exact multiple of 64 system clock cycles (called chips) offset in time from any other base station. The mobile checks all 215 short code offsets to find the strongest pilot signal using the "searcher" special hardware dedicated to doing pilot correlations. After checking all chip offsets the mobile stores signal strengths of any Pilot Channel it hears. When the strongest pilot signal is found the Rake demodulator aligns its self to the short code offset, then applies Walsh code 32 in order to demodulate the Synch Channel. The mobile knows when this Pilot channel and Synch Channel starts but it does not know if it is time slot 1, 45, 248 or what. Figure 36 "CDMA Pilot & Synch Channel Timing" will help you understand how the mobile gets timing and other information from these two channels.

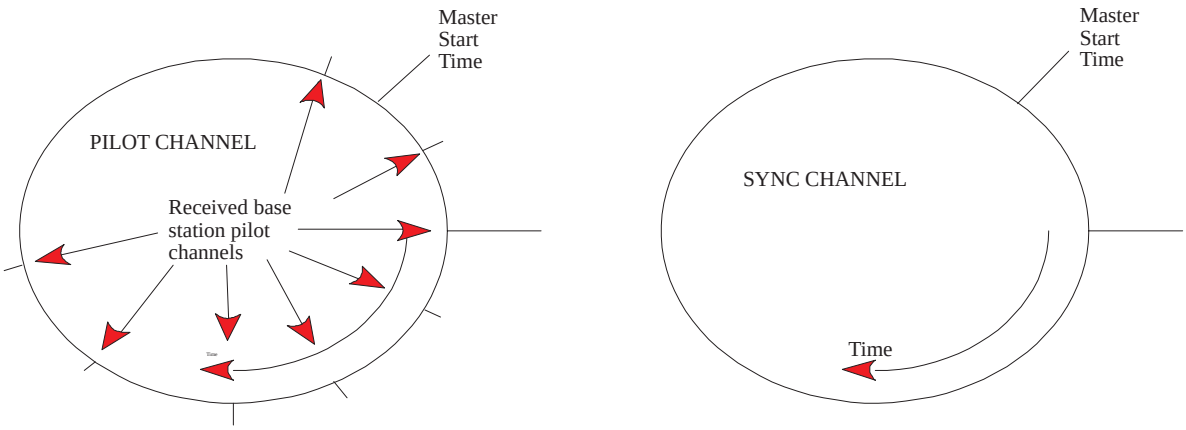

Figure 21. CDMA Pilot & Synch Channel Timing

The Pilot channel circle has small tick marks sticking outside the circle. These tick marks represent signal strengths of the received Pilot channels from surrounding base stations. Each base station's pilot channel is separated from the next by 64 clock chips for a total of 512 different pilot channels. The longest tick on the right side represents the strongest Pilot channel.

Master (System) start time is shown on both circles but the mobile does not know System start time until it decodes the Sync channel. Remember that both the Pilot and Sync channels do not contain a Long Code so they both repeat at the same rate of 26.67 msec. The mobile starts decoding the Synch channel information of the strongest cell site when it acquires that cell's Pilot channel. The mobile does not decode Sync channels of the weaker cell sites received during the search.

Sync Channel

The Sync Channel has a lot of important information, some of which is listed below..
Pilot PN offset of base station: The Pilot PN offset is the base station's time slot number.
System Time*:* Is the MASTER start time.
Local Time Offset from System Time:
Long Code State: This is very important! The state of the "Long Code" 320 milliseconds in the future is sent. The CDMA Long Code was started in Jan 1, 1980 and has been running ever since. Remember this code only repeats its self once every 41 days, so it would take too long to search through the entire code. Not only does the CDMA cellular phone need to know when the present long code sequence started, it also needs to know where the code is "right now". That's what is meant by "Code State".
SID, NID of Cellular System: System Identification, Network Identification
Paging Channel Data Rate: 0, 9600: 1, 4800
Base Station Protocol Revision: 1 – IS95; 2 – IS95A; 3 – TSB74
Leap Seconds From Start of System Time: This is the delay from system time for the clock based on the "slot cycle index".
Daylight Savings Time Flag: Self explanatory.

Paging Channel

Once the mobile has system time and long code state, the Paging channel information can be read. If required the mobile will register with the base station at this time. The phone must register if it is in a slotted mode. When a phone is in a slotted mode it goes to sleep for a few seconds periodically and then wakes up to check for a page. The sleep period based on the "slot cycle Index" must be known to the base station or the phone could be paged while asleep and miss the page.

The following is a partial list of Paging channel information:

System Parameters Message: This message provides the mobile with information, such as network, system and base station identification numbers, the number of paging channels supported, registration information, and the soft hand–off thresholds.

Access Parameters Message: When a mobile calls the base station it uses a channel called the "Access Channel". This message gives the mobile information that dictates the behavior of access probes when a CDMA mobile initiates a call.

Neighbor List Message: The neighbor list gives the mobile the PN Offsets of surrounding cell sites that may become likely candidates for soft hand–offs.

CDMA Channel List Message: The CDMA channel list reports the number of CDMA frequencies supported by the cell station in use as well as surrounding cell site frequencies and configurations.

Slotted Page Message: The Slotted and Non–slotted page messages allow the cell site to page CDMA phones for incoming calls. CDMA mobiles operating in the slotted mode must first register with the cell site before they can be paged. This registration is required to establish which slot will be used by the cell site to transmit the page to the mobile.

Channel Assignment Message: The channel assignment message is used to communicate the information needed to get the mobile onto a traffic channel.

CDMA Call Initiation

When a user keys in a phone number and hits the send key the mobile sends out an "Access Probe". The "Access Channel" is one of the two channels used by a mobile, it is used by the mobile to initiate calls, the other channel is the Traffic channel. The difference between the two channels is in the coding. The Access Channel applies a mask to the Long Code that is derived from information received from the Sync and Paging channels: the information is; paging channel number, access channel number, base station ID, and the Pilot PN offset used by the base station. A new sub–subject comes up at this point, Power Control, which will be discussed in the next sub–topics. Since a two–way link has not been established yet, open loop power control will be used by the mobile to set its transmitter output power. Multiple tries are allowed with random times between tries to prevent two mobiles from consistently transmitting access probes at the same time.

Reverse Link Open Loop Power Control

The key to maximizing CDMA capacity is power control. The limiting factor for CDMA system capacity is total interference. Total interference can best be described as all of the unwanted signals a base station receives. These signals include other CDMA signals, natural back ground noise, and man made interference such as noisy power lines. Ideally a base station would receive all the mobiles signals at the same level. If the mobiles transmit a stronger signal than necessary then more interference would be created and capacity would drop. When a CDMA mobile first tries to contact a base station, open loop power control is used. Open loop power control sets the sum of transmit and receive power to a constant, –73 dBm. The formula is; Transmit Power = (–73) – (Receive Power): all units are in dBm. If a mobile received a base stations signal at –85 dBm the mobiles transmit power would be (–73 dBm) – (–85 dBm) = +12 dBm transmit power.

The mobile's Open Loop power control slew rate is limited to match the slew rate of closed loop power control. If not limited the mobiles power output could swing wildly during sudden reverse link signal strength changes.

A third point must be made before leaving Reverse Link Open Loop Power Control. Suppose the CDMA mobile is traveling between two base stations, one has a large area to cover and transmits signals at high output power.

The second base station is a mini–cell and therefore transmits at a lower power. The mobile would transmit a higher power than necessary to the mini–cell because the weaker signal would be interrupted as a distant station. This problem is taken care of after the mobile has located the strongest base station. Information contained in the Sync Channel of each cell site transmits its characteristics for power control.

CDMA Call

After each access attempt, the mobile listens to the Paging Channel for a response from the base station. When the base station detects the mobiles access probe, it responds with a channel assignment message. This message contains all of the information required to get the mobile onto a traffic channel. Information required for the mobile to start using a traffic channel includes, Walsh code channel to be used for the forward traffic channel, the frequency being used, and the frame offset to indicate the delay between the forward and reverse links. Once this information has been acknowledged by the mobile a move to the designated traffic channel is accomplished. At this point conversations can began. To accommodate traffic other than voice data, two methods of temporarily seizing the traffic channel are used: blank and burst signaling and dim and burst signaling. Blank and burst signaling seizes several blocks of data frames, removes the voice data and replaces it with house keeping data. Dim and burst reduces the VOCODER rate and then uses the remaining traffic channel time to more slowly send house keeping messages.

Reverse Link Closed Loop Power Control

Because of multipath, atmospheric conditions, and the number of CDMA users among other reasons the Open Loop Power Control method is not precise enough. Remember to optimize capacity all CDMA mobile signals should arrive at the base station at the same strength. The base station monitors each mobile's receive signal strength and directs the mobile to raise or lower it's power in 1 dB steps until the signal level is just adequate. One side benefit from lower power output is longer battery life for the mobile.

CDMA Variable Rate Speech Coder

The VOCODER takes advantage of quiet times and less complex parts of speech to raise capacity. An "oooooo" vowel sound is less complex than a word like "fat" or "cat" with consonants in it. It takes more coded samples to reproduce consonants than vowels. During speech activity the VOCODER operates at 9.6 kbps and during pauses the rate will drop to 1.2 kbps. The data rate is based on speech activity and a decision is made every 20 msec as to the rate. The variable rate speech coder saves a great deal of power because the mobile goes to pulsed operation at 4.8 kbps and below. The section on Mobile Power Bursting will explain pulsed operation further.

Mobile Power Bursting

Each 20 millisecond CDMA data frame is divided into sixteen "power control groups". Each power control group contains 1536 data symbols (chips) at a data rate of 1.2288 Mbps which represent 12 encoded voice data bits. Figure 22. Mobile Power Bursting shows the relationship between the four VOCODER data rates.

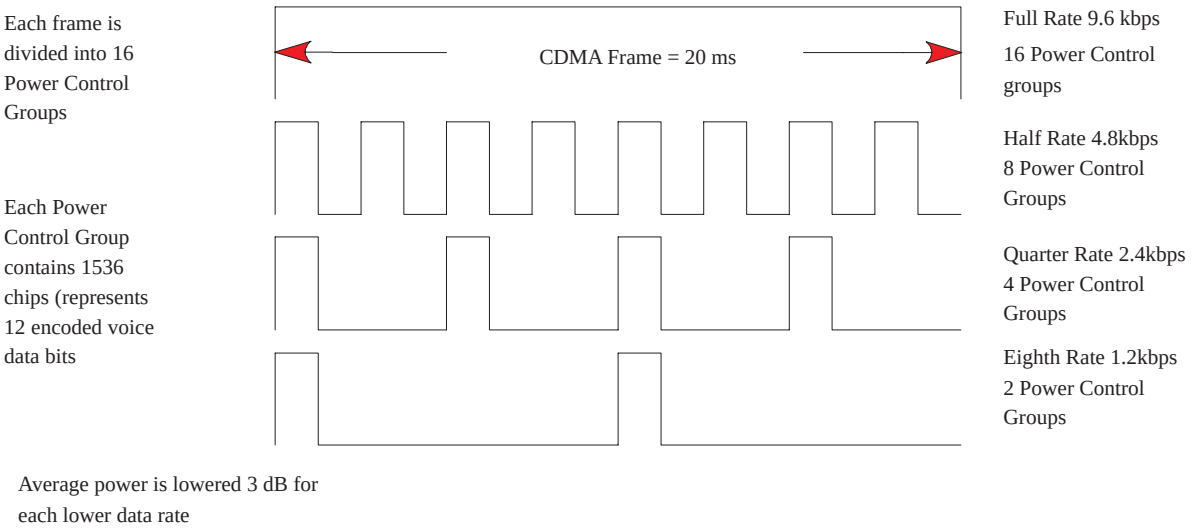
Each frame is divided into 16 Power Control Groups
CDMA Frame = 20 ms
Full Rate 9.6 kbps
16 Power Control groups
Half Rate 4.8kbps
8 Power Control Groups
Each Power Control Group contains 1536 chips (represents 12 encoded voice data bits
Quarter Rate 2.4kbps
4 Power Control Groups
Eighth Rate 1.2kbps
2 Power Control Groups
Average power is lowered 3 dB for each lower data rate

Figure 22. Mobile Power Bursting

Here is how that breaks down: when the VOCODER is running at the full rate of 9600 bps, each 1.25 ms power control group represents 12 encoded voice data bits (0.00125 seconds X 9600 bps = 12 bits). The 1536 number is the number of bits in a 1.25 ms period at a rate of 1.2288 Mbps which is the final spread data rate. The VOCODER can run at 9.6 kbps, 4.8 kbps, 2.4 kbps, and 1.2 kbps for rate set one. When the VOCODER data rate drops below 9.6 kbps the CDMA mobile starts transmitting in bursts. Not only does the mobile save power by turning off the transmitter, each decrease in data rate lowers the average power output by 3 dB, a 50% reduction in radiated power. Average power decrease will result in lower interference to other CDMA signals which will result in capacity increase.

The Rake Receiver

When AMPS and DAMPS cellular phones encounter multipath signal problems, the cure is a very strong signal–to–noise ratio. Remember a CDMA phone receives a “channel” by correlating (matching) the received spread code with an unmodulated internal copy. Mobile CDMA phones have three correlation receivers called a rake receiver. When a CDMA mobile receives signals with different delay times the phone will synchronize to the strongest signal. Usually the strongest signal has arrived via the most direct route. One of the other two receivers will synchronize with the reflected signal, then combine this signal with the direct signal for a much stronger totally combined signal.

One more advantage of CDMA mobiles is utilized when a hand–off to another base station is necessary, a make–before–break soft hand–off is used. The rake receiver constantly searches for and measures multi–path and neighboring signals. The multi–path signals are time adjusted then combined for a stronger total signal. The neighboring cell site signals are used to determine the best choice when a handoff when necessary.

CDMA Hand–offs

Normally CDMA hand–offs are make–before–break and either “Soft” or “Softer”. A Soft hand–off is between base stations at two different locations. A Softer hand–off is between two sectors at the same base station Figure 38, CDMA Hand–off will help explain how soft, make–before–break hand–offs are accomplished.

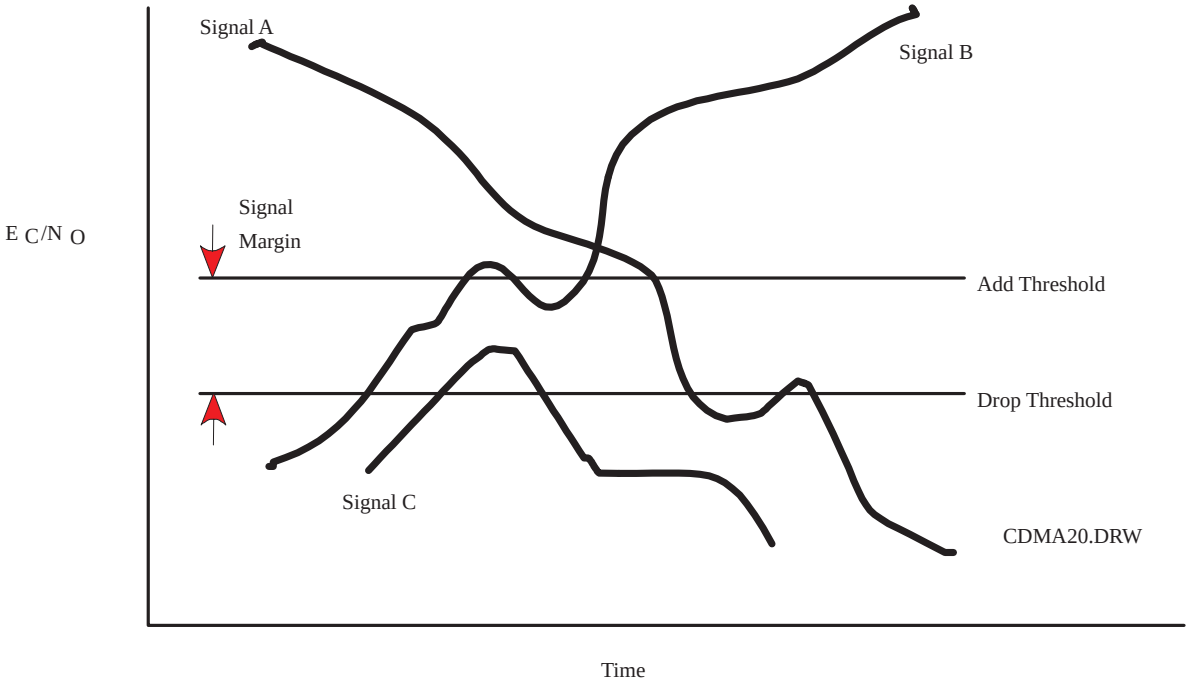

Figure 23. CDMA Hand–off

Once a call is established, the mobile is constantly searching for other possible cell sites that might be good candidate for soft hand–offs. A search list of neighboring base stations from the base station in use is used to look for hand–off candidates.

CDMA Soft Hand–off Initiation
The following scenario describes what has to happen to get a soft hand–off. A mobile with an established call using signal A starts receiving signal B. When signal B exceeds the Add Threshold level as defined by B’s cell site, a pilot strength message is sent to cell site A from the mobile. The pilot strength message is sent on the traffic channel using either dim and burst or blank and burst signaling.

The pilot strength message starts a soft hand–off. When the pilot strength message is received; base station A passes this request to the MTSO (Mobile Telephone Switching Office). The MTSO passes the request to station B to see if a traffic channel is available for the soft hand–off request.

CDMA Soft Hand–off
If a channel is available, cell site B sends the Walsh Code that will be assigned for the soft hand–off to the MTSO. At this point base station A orders the soft hand–off by sending a hand–off direction message to the mobile using the traffic channel. When the hand–off message is acknowledged, the MTSO sends the land link to base station B who then begins to send information on the assigned Walsh code traffic channel to the mobile. The mobile then receives both signals from the two cell sites, each operating on different PN offsets and Walsh coded traffic channels. The two signals are then combined by using the two pilot signals as coherent phase references. In a two way soft hand–off, two of the mobile's rakes are used: one for each received base station At the same time both base stations are independently receiving the mobile's signal. The demodulated signal is sent to the MTSO where the two signal are compared on a frame–by–frame bases. The MTSO selects the best of the two signals and sends that signal to the CODEC where it is passed to the public telephone network.

CDMA Hand–off Completion
When the signal from station A degrades and goes below "Drop Threshold" the mobile sends another pilot strength message to base station B indicating that base station A's link should be terminated. At this point the mobile is being power controlled by base station B. The mobiles request is passed by the MTSO to cell site A to terminate transmission and reception of the mobile's signal. The mobile is now exclusively terminated with base station B.

If the hand–offs are between sectors on a base station the same routine applies. It makes no difference to the mobile whether the hand–off is between sectors or cell sites.

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